

Multi-Decadal Nitrogen Dioxide and Derived Products from Satellites (MINDS) Datasets Released by NASA GES DISC and Their Applications for Air Quality

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Acknowledgments: Lok N. Lamsal, Nickolay A. Krotkov,
Peter Leonard from MINDS Project



Multi-Decadal Nitrogen Dioxide and Derived Products from Satellites (MINDS)

- A NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Project
- Goal: To develop long-term (1995 to present) NO₂ global data records by adapting a consistent retrieval algorithm to multiple instrument measurements
- Multiple instruments:
 1. Global Ozone Monitoring Experiment (GOME, 1995-2003) onboard the second European Remote Sensing satellite (ERS-2)
 2. GOME-2 on the Meteorological Operational satellites (MetOp-A and MetOp-B, 2006 -)
 3. Ozone Monitoring Instrument (OMI, 2004 -) onboard the Aura satellite
 4. TROPospheric Monitoring Instrument (TROPOMI, 2017 -) onboard the Copernicus Sentinel-5 Precursor (S5P)
 5. Scanning Imaging Spectrometer for Atmospheric Cartography (SCIAMACHY, 2002-2012) onboard the ENVironmental SATellite (ENVISAT)



Challenges and Approach

- Challenges

1. Differences in instrument & measurement characteristics
2. Differences in retrieval algorithms & inputs, affecting data accuracy and inter-satellite data consistency

- Approach

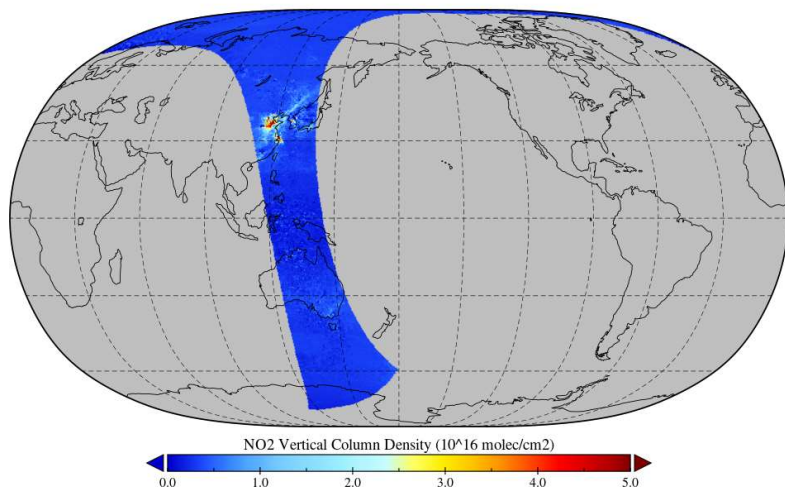
Apply coupled surface reflectivity-cloud-NO₂ algorithms for all sensors and enhance the quality of auxiliary data, including model-derived *a priori* information

(Courtesy of Lok Lamsal et al., 2021 AGU Fall Meeting)

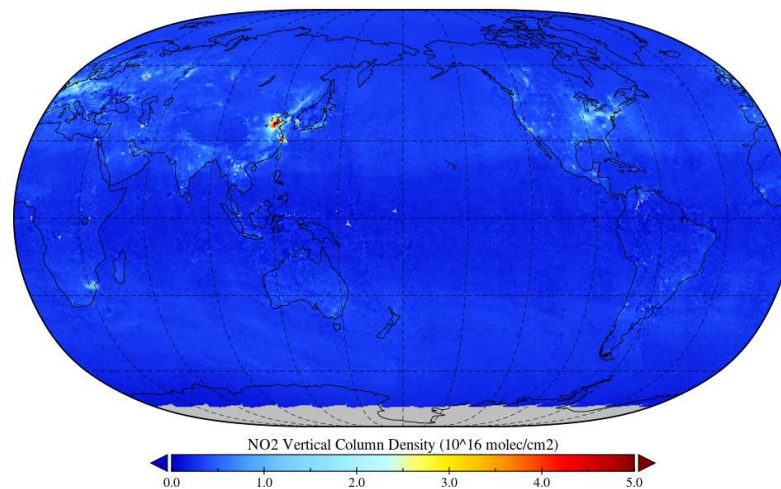
Published MINDS V1.1 Products

Product	Spatial Resolution	Short Name	Temporal Coverage	DOI
OMI/Aura NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath	13 km x 24 km	OMI_MINDS_NO2	2004 -	10.5067/MEASURES/MINDS/DATA204
OMI/Aura NO2 Tropospheric, Stratospheric and Total Columns MINDS Daily L2 Global Gridded	0.25 degree x 0.25 degree	OMI_MINDS_NO2G	2004 -	10.5067/MEASURES/MINDS/DATA214
OMI/Aura NO2 Tropospheric, Stratospheric and Total Columns MINDS Daily L3 Global Gridded	0.25 degree x 0.25 degree	OMI_MINDS_NO2d	2004 -	10.5067/MEASURES/MINDS/DATA304
TROPOMI/S5P NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath	5.5 km x 3.5 km	TROPOMI_MINDS_NO2	2018 -	10.5067/MEASURES/MINDS/DATA203
GOME/ERS-2 NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath	40 km x 320 km	GOME_MINDS_NO2	1995 - 2003	10.5067/MEASURES/MINDS/DATA202

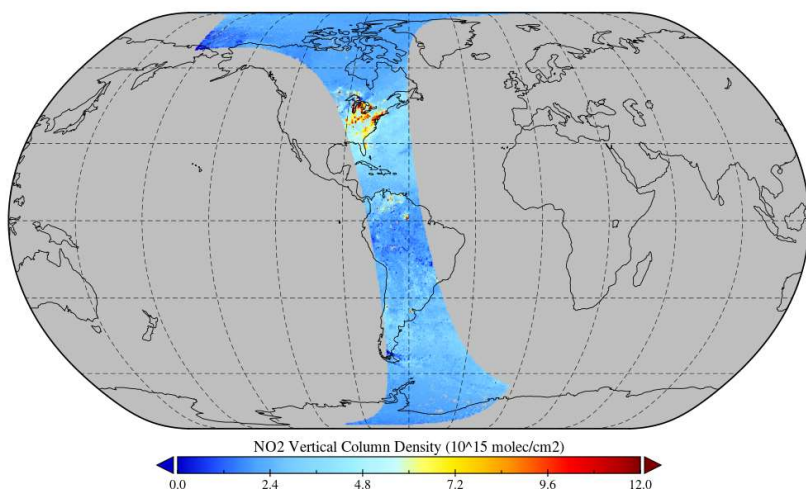
OMI_MINDS_NO2 NO2 Total Column Amount for 2005-04-12 (Orbit 3945)



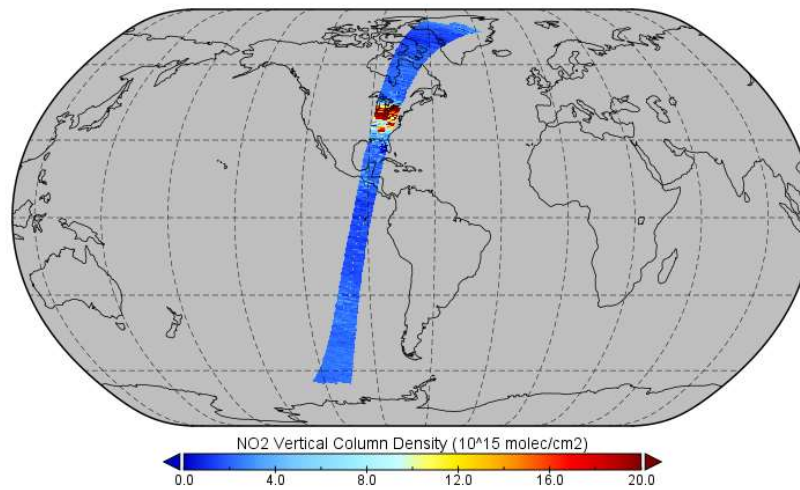
OMI_MINDS_NO2d NO2 Total Column Amount for 2005-04-12



TROPOMI_MINDS_NO2 NO2 Total Column Amount for 2019-03-27 (Orbit 07524)



GOME_MINDS_NO2 NO2 Total Column Amount for 2002-03-07 (Orbit 35966)



MINDS
Data
Products
Sample
Images

Search MINDS Products on GES DISC Webpage

https://disc.gsfc.nasa.gov/

GES DISC Search: Showing 1 - 5 of 5 datasets associated with MINDS

https://disc.gsfc.nasa.gov/datasets?keywords=MINDS&page=1

COVID-19 Therapie...

Other bookmarks

GES DISC Find a DAAC -

Atmospheric Composition, Water & Energy Cycles and Climate Variability

My Dashboard

Data Collections Showing 1 - 5 of 5 datasets associated with MINDS

Refine By

Subject Sort ▾

☐ Atmospheric Chemistry (5)

Measurement Sort ▾

☐ Atmospheric Nitric Acid (5)

☐ Nitric Oxide (5)

☐ Nitrogen Dioxide (5)

☐ Nitrogen Oxides (5)

☐ Nitrous Oxide (5)

Source Sort ▾

☐ Aura OMI (3)

☐ ERS-2 GOME (1)

☐ Sentinel-5P TROPOMI (1)

Processing Level Sort ▾

☐ 2 (3)

☐ 3 (1)

☐ 2G (1)

Project Sort ▾

☐ MEASURES (5)

Temporal Resolution Sort ▾

☐ 98.8 minutes (1)

☐ 100 minutes (1)

☐ 101.5 minutes (1)

☐ 1 day (2)






Spatial Resolution Sort ▾

☐ 5.5 km x 3.5 km (1)

☐ 13 km x 24 km (1)

☐ 0.25 ° x 0.25 ° (2)

☐ 40 km x 320 km (1)

Dataset	Source	Version	Time Res.	Spatial Res.	Process Level	Begin Date	End Date
 OMI/Aura NO2 Tropospheric, Stratospheric & Total Columns MINDS Daily L3 Global Gridded 0.25 degree x 0.25 degree (OMI_MINDS_NO2d 1.1) Subset / Get Data	Aura OMI	1.1	1 day	0.25 ° x 0.25 °	3	2004-10-01	2022-11-29
 OMI/Aura NO2 Tropospheric, Stratospheric & Total Columns MINDS Daily L2 Global Gridded 0.25 degree x 0.25 degree (OMI_MINDS_NO2G 1.1) Get Data	Aura OMI	1.1	1 day	0.25 ° x 0.25 °	2G	2004-10-01	2022-11-29
 OMI/Aura NO2 Tropospheric, Stratospheric & Total Columns MINDS 1-Orbit L2 Swath 13 km x 24 km (OMI_MINDS_NO2 1.1) Subset / Get Data	Aura OMI	1.1	98.8 minutes	13 km x 24 km	2	2004-10-01	2022-11-30
 GOME/ERS-2 NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 40 km x 320 km (GOME_MINDS_NO2 1.1) Subset / Get Data	ERS-2 GOME	1.1	100 minutes	40 km x 320 km	2	1996-01-01	2003-06-22
 TROPOMI/S5P NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 5.5 km x 3.5 km (TROPOMI_MINDS_NO2 1.1) Subset / Get Data	Sentinel-5P TROPOMI	1.1	101.5 minutes	5.5 km x 3.5 km	2	2018-05-01	2022-01-01

TROPOMI MINDS L2 Dataset Landing Page

Level 2 Subsetter to Collocate L2 Pixel with In-situ Surface Observation

GES DISC Dataset: TROPOMI/S5P

+

← → ↻ 🏠 🔒

https://disc.gsfc.nasa.gov/datasets/TROPOMI_MINDS_NO2_1.1/summary?keywords=MINDS

🔗 ☆ ⚙️ 🖨️ 👤 ⋮

COVID-19 Therapie... Other bookmarks

EARTHDATA

Find a DAAC ▾

?

GES DISC

Data Collections ▾ MINDS

📅 📖 🔍

⚠️² Feedback Cloud Migration Help ▾

Login

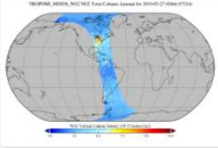
My Dashboard

[Atmospheric Composition](#), [Water & Energy Cycles](#) and [Climate Variability](#)

Back to search results

Making Earth System Data Records for Use in Research Environments

TROPOMI/S5P NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 5.5 km x 3.5 km (TROPOMI_MINDS_NO2)



View Full-size Image

As part of the NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program, this project entitled "Multi-Decadal Nitrogen Dioxide and Derived Products from Satellites (MINDS)" will develop consistent long-term global trend-quality data records spanning the last two decades, over which remarkable changes in nitrogen oxides (NOx) emissions have occurred. The objective of the project is to adapt Ozone Monitoring Instrument (OMI) operational algorithms to other satellite instruments and create consistent multi-satellite L2 and L3 nitrogen dioxide (NO2) columns and value-added L4 surface NO2 concentrations and NOx emissions data products, systematically accounting for instrumental differences. The instruments include Global Ozone Monitoring Experiment (GOME, 1996-2011), SCanning Imaging Absorption spectroMeter for Atmospheric CHartography (SCIAMACHY, 2002-2012), OMI (2004-present), GOME-2 (2007-present), and TROPOspheric Monitoring Instrument (TROPOMI, 2018-p [...more](#))

Data Access

Online Archive

Earthdata Search

OPENDAP

📄 Subset / Get Data

Product Summary

Data Citation

Documentation

Data Calendar

Shortname:

TROPOMI_MINDS_NO2

Longname:

TROPOMI/S5P NO2 Tropospheric, Stratospheric and Total Columns MINDS 1-Orbit L2 Swath 5.5 km x 3.5 km

DOI:

10.5067/MEASURES/MINDS/DATA203

Version:

1.1

S5P_L2_NO2___HiR_2/summary?keywords=S5P_L2_NO2___HiR_2

Download Method: ☒ Get File Subsets using the GES DISC Subsetter Reset

☐ Get Original Files
Generate unmodified file links directly from the archive.


☒ Get File Subsets using the GES DISC Subsetter Help
Generate file links supporting geo-spatial search and crop, selection of variables, selection of time of day, and data presentation, in netCDF format.

Method Options ?

Refine Date Range: ☒ 2021-12-01 00:00:00 to 2021-12-31 23:59:59 Reset

Refine Region: ☒ 39.372, -76.747 Reset

39.372 -76.747 Default Range



Available Range: -180, -90, 180, 90 Cursor Coordinates: 34.127, -67.324

☒ Use 'Refine Region' for geo-spatial subsetting ?

Variables: ☒ 1 variable(s) selected Reset

Time of Day: Get complete time span Reset

Data Presentation: CROP Reset

☐ VECTOR: Spatial dimensions will be reduced to a single data stream dimension.

☒ CROP: Spatial dimensions will be trimmed to data.

☐ FULL: Spatial dimensions will remain at original lengths.

References

Shortname: S5P_L2_NO2___HiR_2

Longname: S5P_L2_NO2___HiR_2

DOI: S5P_L2_NO2___HiR_2

Version: S5P_L2_NO2___HiR_2

Format: S5P_L2_NO2___HiR_2

Initial Coverage: S5P_L2_NO2___HiR_2

Oral Coverage: S5P_L2_NO2___HiR_2

File Size: S5P_L2_NO2___HiR_2

Data Resolution: S5P_L2_NO2___HiR_2

Spatial: S5P_L2_NO2___HiR_2

Temporal: S5P_L2_NO2___HiR_2

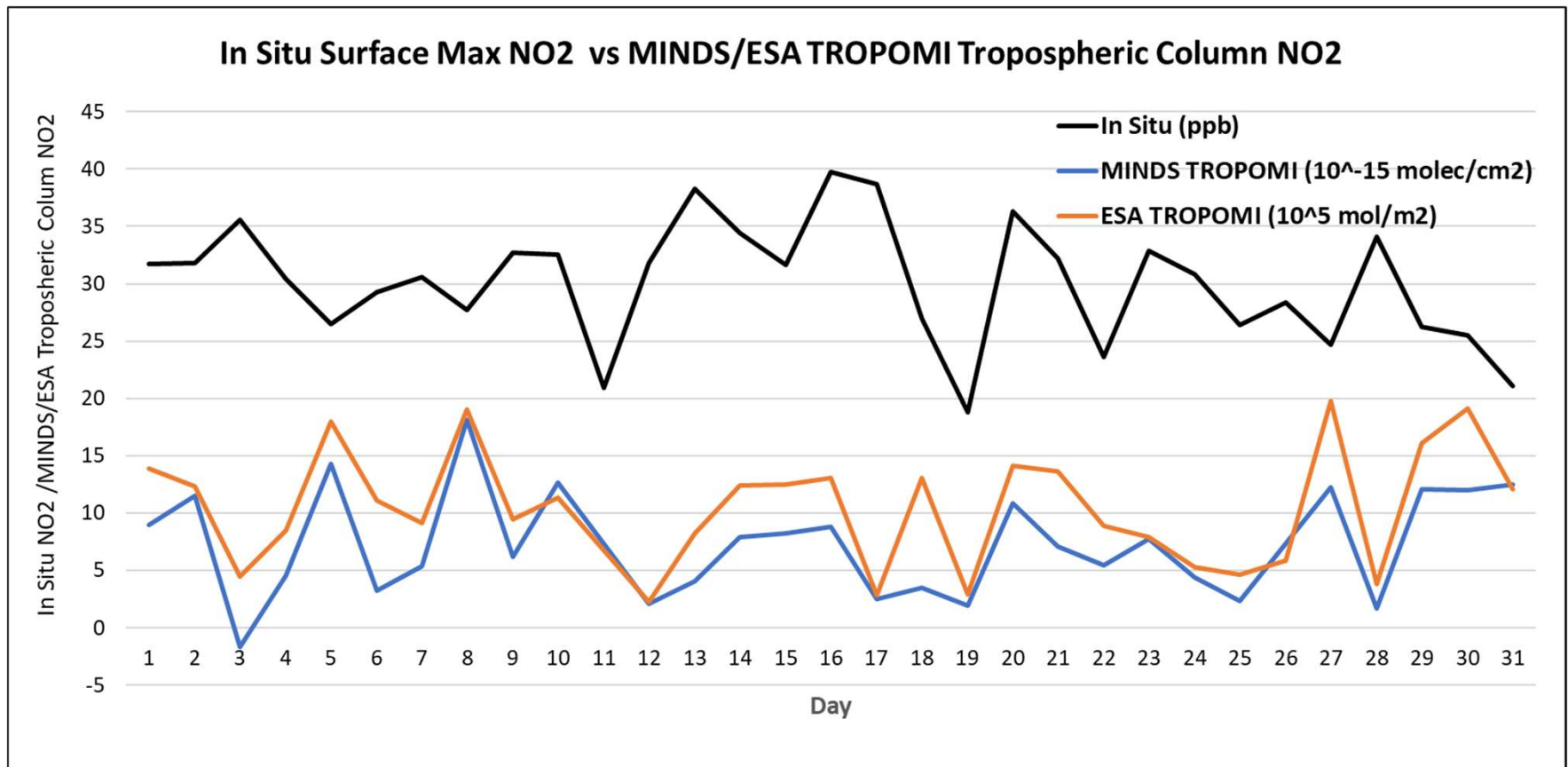
Subset/Get Data: A Level-2 Subsetter Use Case

How to Subset Level-2 Data

<https://disc.gsfc.nasa.gov/information/howto?keywords=Level%20%20Subsetter&title=How%20to%20Subset%20Level-2%20Data>



NO₂ Daily Change at Baltimore County, MD (EPA Site ID 24005009) in December 2021



Giovanni - Exploring/Analyzing L3/L4 Data

<https://giovanni.gsfc.nasa.gov/>

Giovanni - Data Selection

giovanni.gsfc.nasa.gov/giovanni/#service=QuCI&seasons=&starttime=2016-01-01T00:00:00Z&endtime=2021-12-31T23:59:59Z&bbox=90,20,125,50&data=OMNO2d_003_ColumnAmou...

COVID-19 Therapie... Other bookmarks

EARTHDATA Find a DAAC

GIOVANNI The Bridge Between Data and Science v 4.37 Feedback Help Log out (fengding)

Select Plot
Map, Recurring Averages

Select Seasonal Dates
Enter days, months or seasons 2016 to 2021
Valid Range: 2004-10-01 to 2022-11-06
Enter days, months or seasons

Select Region (Bounding Box or Shape)
90,20,125,50

Select Variables

Observations

☐ Model (1)
☐ Observation (2)

Disciplines

☐ Atmospheric Chemistry (2)
☐ Atmospheric Dynamics (1)
☐ Water and Energy Cycle (1)

Measurements

Platform / Instrument

Spatial Resolutions

Temporal Resolutions

Portal

Number of matching Variables: 3 of 2011 Total Variable(s) included in Plot: 1

Keyword: NO2 Search Clear

	Variable	Units	Source	Temp. Res.	Spat. Res.	Begin Date	End Date
<input checked="" type="checkbox"/>	NO2 Total Column (30% Cloud Screened) (OMNO2d v003)	molecules/cm ²	OMI	Daily	0.25 °	2004-10-01	2022-11-02
<input type="checkbox"/>	NO2 Tropospheric Column (30% Cloud Screened) (OMNO2d v003)	molecules/cm ²	OMI	Daily	0.25 °	2004-10-01	2022-11-06
<input type="checkbox"/>	Upwelling longwave flux at toa (clear sky and no aerosol) (M2TMNXRAD v5.12.4)	W m ⁻²	MERRA-2 Model	Monthly	0.5 x 0.625 °	1980-01-01	2022-09-30

Responsible NASA Official: [Angela Li](#)
Web Curator: [M. Hegde](#)

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Reset Plot Data Go to Results

Giovanni: Recurring Averages Map

Study COVID-19 Impact on NO₂ in April 2022, Eastern China

Giovanni - Data Selection

giovanni.gsfc.nasa.gov/giovanni/#service=QuCl&seasons=101106&starttime=2016-01-01T00:00:00Z&endtime=2021-12-31T23:59:59Z&bbox=90,20,125,50&data=OMNO2d_003_Colum...

COVID-19 Therapie...

Other bookmarks

EARTHDATA Find a DAAC

GIOVANNI The Bridge Between Data and Science v 4.37 Feedback Help Log out (fengding)

Select Plot Select Seasonal Dates Select Region (Bounding Box or Shape)

Map, Recurring Averages 04-11, 04-16 2016 to 2021 90,20,125,50

Maps

- Time Averaged Map
- Map, Recurring Averages**
- Time Averaged Overlay Map
- Map, Accumulated
- Animation
Limited to: 365 time steps
- Map, Difference of Time Averaged

Comparisons

- Map, Correlation

Time Series

- Scatter, Area Averaged (Static)
- Scatter (Interactive)
Limited to: 30000 points
- Scatter (Static)
- Scatter, Time-Averaged (Interactive)
Limited to: 30000 points
- Time Series, Recurring Averages
- Miscellaneous
 - Histogram
 - Zonal Mean
- Vertical
 - Cross Section, Latitude-Pressure
 - Cross Section, Longitude-Pressure
 - Cross Section, Time-Pressure
 - Vertical Profile

Measurements

- Platform / Instrument**
- Spatial Resolutions**
- Temporal Resolutions**
- Wavelengths**



	Source	Temp. Res.	Spat. Res.	Begin Date	End Date
iles/cm²	OMI	Daily	0.25 °	2004-10-01	2022-11-02

Responsible NASA Official: [Angela Li](#) Privacy Powered By ▲ Contact Us

Reset Plot Data Go to Results

Giovanni – Select Days, Months, Seasons, Year Range

Days: 4/11–04/16 Year Range: 2006-2010, 2011-2015, 2016-2021, 2022

 EARTHDATA Find a DAAC 

GIOVANNI

 The Bridge Between Data and Science Feedback Help Log out (fengding)

Select Plot

Map, Recurring Averages

Select Variables

Observations

- ☐ Model (1066)
- ☐ Observation (709)

Disciplines

- ☐ Aerosols (253)
- ☐ Atmospheric Chemistry (228)
- ☐ Atmospheric Dynamics (733)
- ☐ Cryosphere (16)
- ☐ Hydrology (501)
- ☐ Ocean Biology (31)
- ☐ Oceanography (48)
- ☐ Water and Energy Cycle (682)

Measurements

Platform / Instrument

Spatial Resolutions

Temporal Resolutions

Wavelengths

Select Seasonal Dates

04-11, 04-16

2016 to 2021

Select Region (Bounding Box or Shape)

90,20,125,50

☒ Days ☐ Months ☐ Seasons

April

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

to April

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

☐ Days ☒ Months ☐ Seasons

- ☐ January ☐ July
- ☐ February ☐ August
- ☐ March ☐ September
- ☐ April ☐ October
- ☐ May ☐ November
- ☐ June ☐ December

☐ Days ☐ Months ☒ Seasons

- ☐ DJF
- ☐ MAM
- ☐ JJA
- ☐ SON

Reset

Plot Data

Go to Results

Giovanni – Select Region (Bounding Box or Shape)

Bounding Box: Central and Eastern China

Giovanni - Data Selection

giovanni.gsfc.nasa.gov/giovanni/#service=QuCI&seasons=101106&starttime=2016-01-01T00:00:00Z&endtime=2021-12-31T23:59:59Z&bbox=90,20,125,50&data=OMNO2d_003_Colum...

COVID-19 Therapie...

EARTHDATA Find a DAAC

GIOVANNI The Bridge Between Data and Science v 4.37 Feedback Help Log out (fengding)

Select Plot: Map, Recurring Averages

Select Seasonal Dates: 04-11, 04-16 2016 to 2021

Select Region (Bounding Box or Shape): 90,20,125,50

Select Variables:

- Observations
 - ☐ Model (1066)
 - ☐ Observation (709)
- Disciplines
 - ☐ Aerosols (253)
 - ☐ Atmospheric Chemistry (228)
 - ☐ Atmospheric Dynamics (733)
 - ☐ Cryosphere (16)
 - ☐ Hydrology (501)
 - ☐ Ocean Biology (31)
 - ☐ Oceanography (48)
 - ☐ Water and Energy Cycle (682)
- Measurements
- Platform / Instrument
- Spatial Resolutions
- Temporal Resolutions
- Wavelengths

Number of Variables: 1

Keyword: No

Select a Shape...

- Countries and Areas (source: [US State Department](#))
- Lakes and Reservoirs (source: [World Wildlife Fund](#))
- Land Only file (source: [GES DISC](#))
- Sea Only file (source: [GES DISC](#))
- US States (source: [TIGER/Line, US Census Bureau](#))
- Watersheds (source: [Major Hydrological Basins, FAO \(United Nations\)](#))
- World_Regions (source: [ESRI](#))

Select a Shape...

21°53'N, 79°06'E

40°00'N

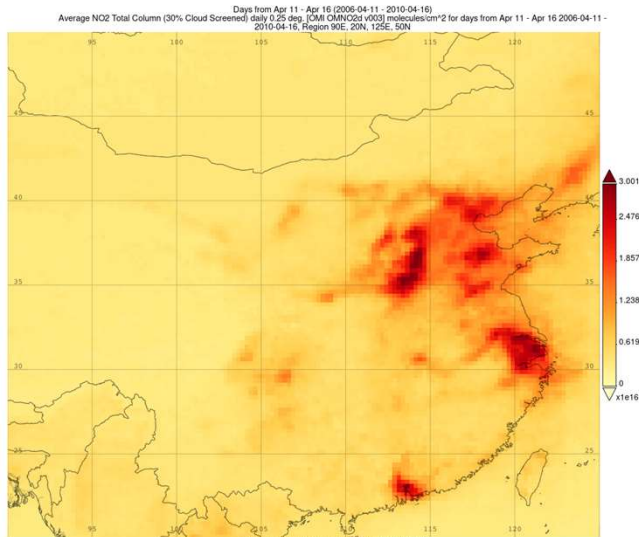
20°00'N

80°00'E 100°00'E 120°00'E 140°00'E

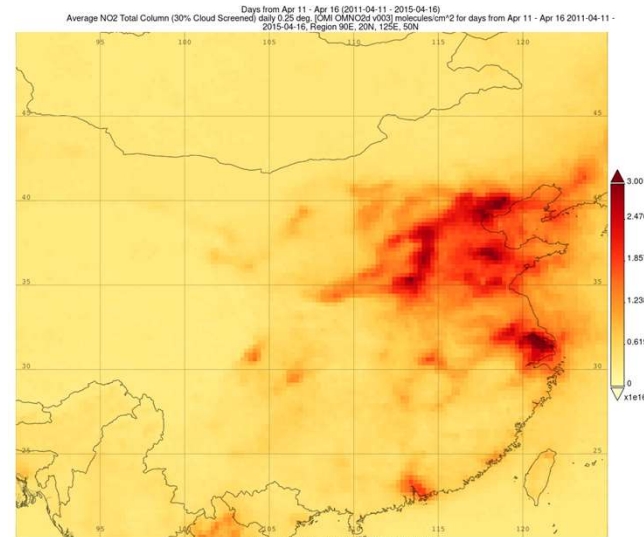
Responsible NASA Official: [Angela Li](#)
Web Curator: [M. Hegde](#) Privacy Powered By ▲ Contact Us

Reset Plot Data Go to Results

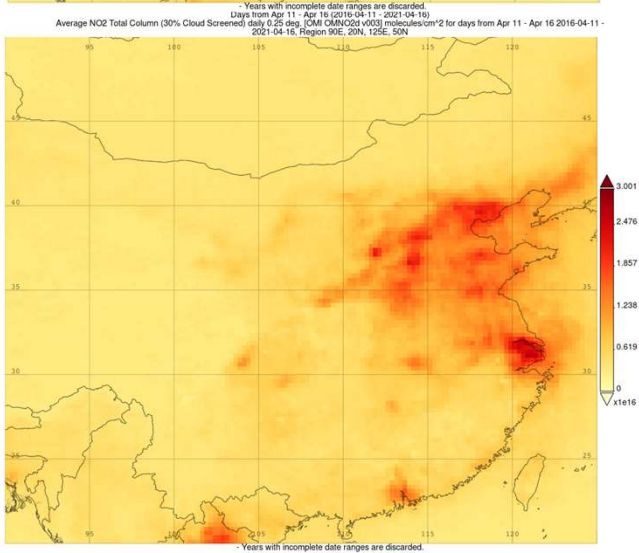
Six-Day (4/11 – 4/16) NO₂ Average



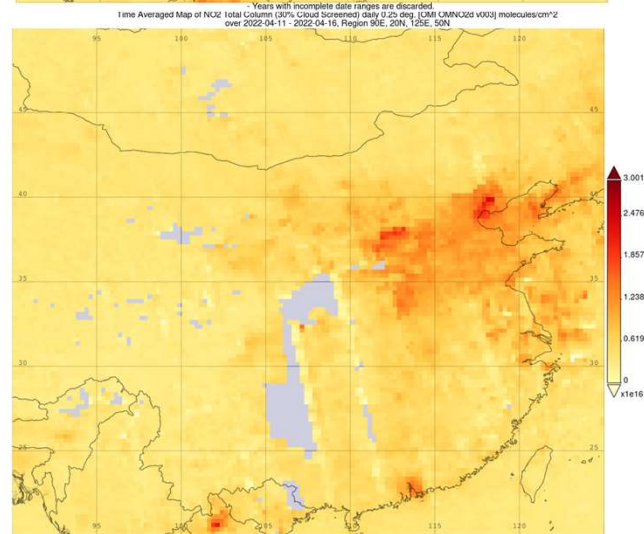
2006
-
2010



2011
-
2015



2016
-
2021



2022

GES DISC Data Migration to Cloud

- Data migration to cloud is ongoing and updates are posted on the GES DISC Cloud Migration Page:
<https://disc.gsfc.nasa.gov/information/documents?title=Migrating%20to%20the%20Cloud>
- All of GES DISC's traditional services and download methods are still available
- Free data download will continue and won't change, i.e., a user only pays cloud computing service but not NASA data
- In-cloud AWS direct S3 access is available

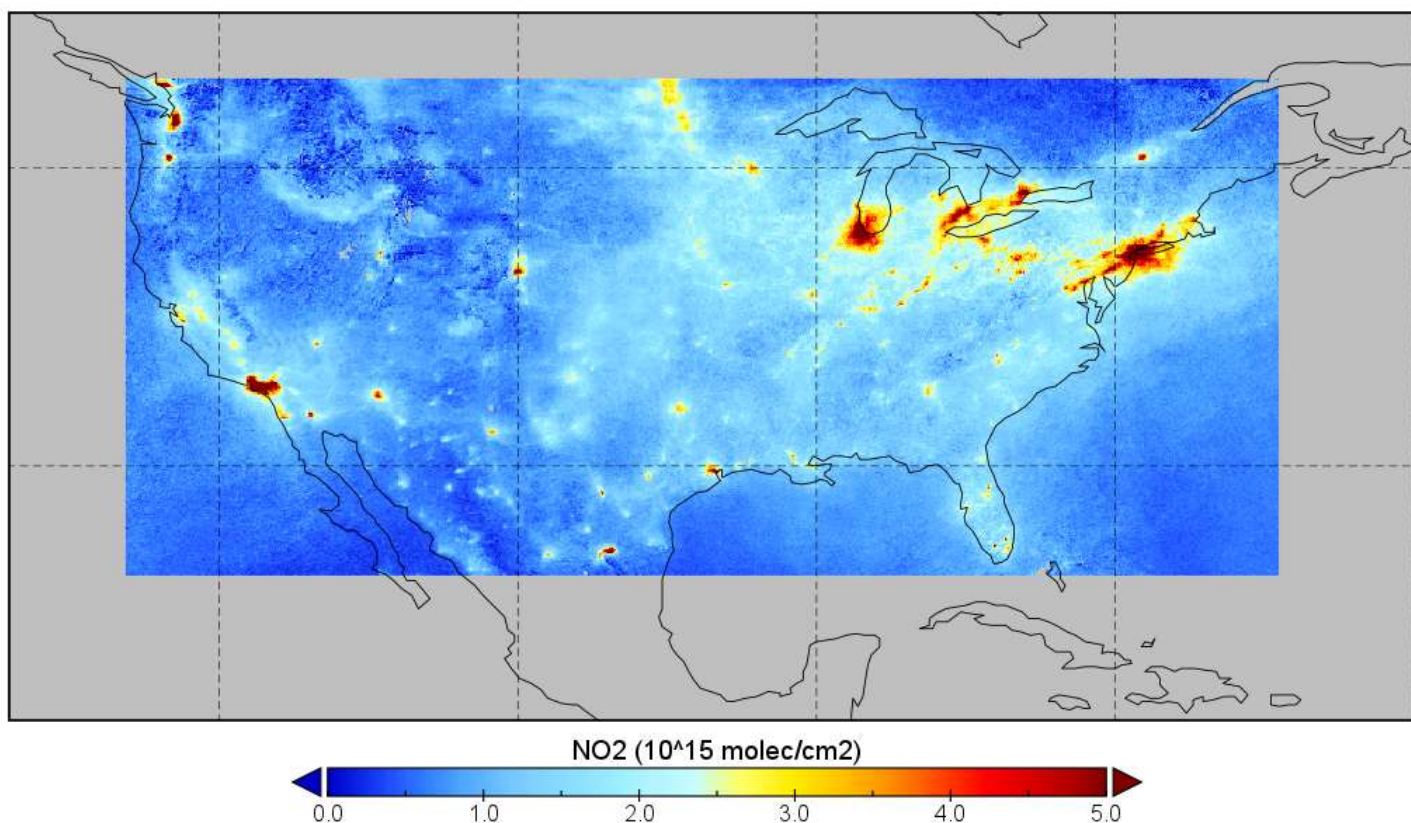
No need to download the data for research and application

One example: generating user-defined Level 3/Level 4 products by directly accessing Level 2 data without downloading



User-defined L3 TROPOMI Gridded Monthly NO₂ with QC over CONUS from NASA HAQAST (Health and Air Quality Application Science Team)

May 2018 Monthly NO₂



Summary

- In addition to many already distributed products (OMI, TROPOMI, MERRA-2), GES DISC released new products from MINDS project for air quality research and application communities
- Level 2 Subsetter and Giovanni are valuable tools to download, explore, and analyze data
- GES DISC data migration to cloud is ongoing and will add more convenient ways to access data
- User feedback is very welcome:
<https://disc.gsfc.nasa.gov> gsfc-dl-help-disc@mail.nasa.gov

